7. PHYTOPLANKTON AND MICROBIAL PLANKTON OF THE NORTHEAST ATLANTIC SHELF

Joe Silke, Kevin Kennington, Eileen Bresnan, and Caroline Cusack

The Northeast Atlantic Shelf region includes the sites from all coastal waters of Ireland, the Irish Sea, and western Scottish and Norwegian Sea waters. The region was defined by WGPME to include locations on the northern margin of Europe that were outside the North Sea/English Channel influence. The character of sites in the region are shallow, coastal-water sites ranging from sheltered bays on the south coast of Ireland and fjordic sea lochs of Scotland to fully exposed locations on the west coasts of Ireland and Scotland. Bathymetry of the region ranges from shallow embayments to regions of shallow, exposed continental-shelf waters. The topography of the shelf drops rapidly to 80–100 m within 20 km of the coast, where it extends to the shelf edge as a relatively flat plateau.

Waters are generally fully saline, with all of the bay sites fully open to oceanic waters. Although the sites would all be considered marine, local impact on salinity from regional river-basin discharge may be observed during seasonal run-off. In terms of anthropogenic inputs, the sites ranged from isolated areas, with little adjacent habitation, to sites close to densely populated areas, moderately industrial zones, and, in some cases, land intensively used for agriculture.

Water currents in the region are dominated by a north-flowing coastal current which flows during summer in a continuous pathway from the northern Cornish coast along the west of Ireland to Malin Head and onwards to The Minch, with average residual velocities >7.5 cm s^{-1} (Fernand *et al.*, 2006). This pathway is potentially a rapid transport mechanism for contaminants and exotic species of plankton. The region is also exposed to Atlantic weather systems, with average wind speeds in January of 12 m s^{-1}. Even during the calmest month of June, the average is 7 m s^{-1}. Consequently, wind plays a significant role in determining the residual circulation of the region. There is evidence that circulation around the southwestern tip of Ireland exists. It has also been demonstrated that this "gateway" may be closed by prevailing southwesterly winds leading to a gyre in the northwestern Celtic Sea. When easterly winds are established, this gateway opens and Celtic Sea water flows around into the mouths of the bays of southwest Ireland. It has been demonstrated that this may determine the advection and dispersion of nutrients and phytoplankton, and is likely to play a significant role in determining the timing and location of harmful algal events in the region (Raine *et al.*, 1993). Water circulation in the Irish Sea is modulated by the presence of fronts and gyres in the central west Irish Sea.

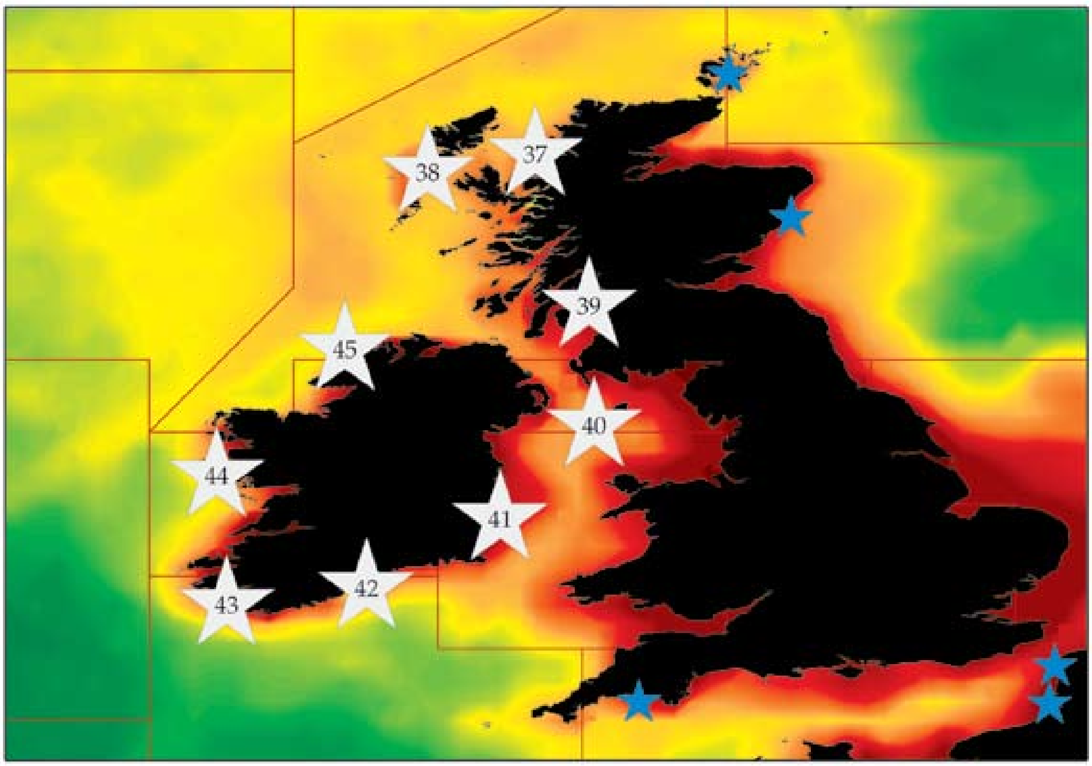


Figure 7.1
Locations of the Northeast Atlantic Shelf plankton monitoring areas (Sites 37–45) plotted on a map of average chlorophyll concentration. Blue stars indicate locations of sites located in the adjacent North Sea and English Channel region (see Section 6).

Time-series of phytoplankton data from the Atlantic Shelf exhibit a typical seasonal pattern of temperate waters, with considerable geographical and temporal variation. The well-mixed winter conditions lead to a region-wide strong spring bloom observed at all sites. The ensuing decrease in nutrient levels lead to a variable summer period characterized by stratified conditions in coastal areas and periodic blooms of mixed or occasionally monospecific diatom and dinoflagellate composition. The growth period tails off in autumn, when a secondary bloom may occur in response to increased mixing and breakdown of the summer thermocline. The seasonal cycle returns to a quiescent winter phase, with generally mixed conditions, light limitation, and increased nutrients return.

Seasonal stabilization and destabilization of the water column in this region accounts for most of the natural variation in both phytoplankton species composition and biomass. Much of the remaining natural variability can be explained by the interaction of phytoplankton with a number of oceanographic features and processes, such as the presence of tidal and thermohaline fronts, wind, topographically associated coastal upwelling, advection landward of offshore water masses, and the flow of coastal and oceanic currents. In estuarine waters, the scenario is somewhat reversed, and although seasonality is important in broad terms, the structure of phytoplankton populations is determined more by local factors operating over much smaller time-scales in the order of days and weeks.

Scottish sites

The northern sites of this region were selected from Scottish coastal waters and were monitoring sites maintained by Marine Scotland Science as part of their Coastal Ecosystem Monitoring Programme. The most northerly, Loch Ewe, is a sea loch on the northwest coast of Scotland. Monitoring has been performed at this site since 2002. Loch Ewe is a fjordic sealoch that opens to the north and has a strong tidal circulation. Situated on the island of North Uist on the Western Isles, Loch Maddy has also been included in the programme since 2003. It is a unique site with a diverse saline lagoon system opening into the sea loch, which contains a mix of rocky reefs and soft sediment habitats. It has been designated a marine special area of conservation. Farther south, within the Firth of Clyde, is Millport on the island of Cumbrae. The Clyde is a wide fjord containing a deep basin separated from a north channel by a sill. A front exists above the sill throughout the year, separating the tidally mixed water in the north channel from the more stratified Firth. Phytoplankton monitoring has been performed at this site since 2005.

Irish Sea

Two sites were included in the Irish Sea proper, which were located at the Isle of Man and one of the Irish coastal regions along the east coast.

The Isle of Man Cypris Station was established in the 1950s, approximately 5 km west of Port Erin in water of 37 m depth. Initially, measurements of salinity, temperature, and soluble reactive phosphorus were recorded (1954). Over the years, other variables were also added, including silicate (1958), total oxidized nitrogen (1960), chlorophyll (1966), and phytoplankton (1995).

This programme continues today and provides one of the longest nutrient chemistry time-series in existence. Data collected from this site have been published in several peer-reviewed publications. Mean annual sea surface temperature at the site has risen by approximately 0.7°C over the duration of the time-series (1904–2012). These temperature increases follow the broad-scale northern hemisphere atmospheric temperature shifts. Eight of the ten warmest ranked years for local SST have occurred in the last 10 years. There is a positive correlation between the Port Erin breakwater salinity measurements and the North Atlantic Oscillation (NAO) index, reflecting the tendency for warmer European winters during NAO positive years.

Nutrient salt concentrations are at a maximum during winter. There is considerable interannual variation in the timing of the winter nutrient maxima, which, at the Cypris Station, occurs between January and March. In spring, with increasing insolation and phytoplankton growth, stocks of nutrient salts are rapidly depleted, reaching a minimum around late spring. Levels remain low until late summer and early autumn, when organic-decay cycles regenerate nutrient salts to the water column. Winter inorganic nutrient data represent the basal or resting state when biological processes have come to a halt and the regeneration of nutrients is complete (Gowen *et al.*, 2002).

Irish coastal sites

The remaining sites are located in coastal areas around Ireland. These five sites are the combination of a national monitoring programme in place since 1990 for the monitoring of harmful algal blooms. The five sites are made up of five coastal stretches (east, south, southwest, west, and northwest), and the individual sample sites where full phytoplankton counts were made within each of these regions were quality checked and combined to represent each of these regions. The east stretch represents sites on the Irish Sea side of Ireland consisting of two sheltered shallow coastal bays. The southern sites are more exposed, with openings to the Celtic Sea. Sites in the southwest were made up of locations in the long inlets in this area. These sites were also in locations important to the aquaculture industry, particularly mussel farming. Farther up along the west coast were locations of both shellfish farming and salmon farms, which have a particular interest in the phytoplankton monitoring programme and provide useful access to samples.

7.1 Loch Ewe (Site 37)

Eileen Bresnan

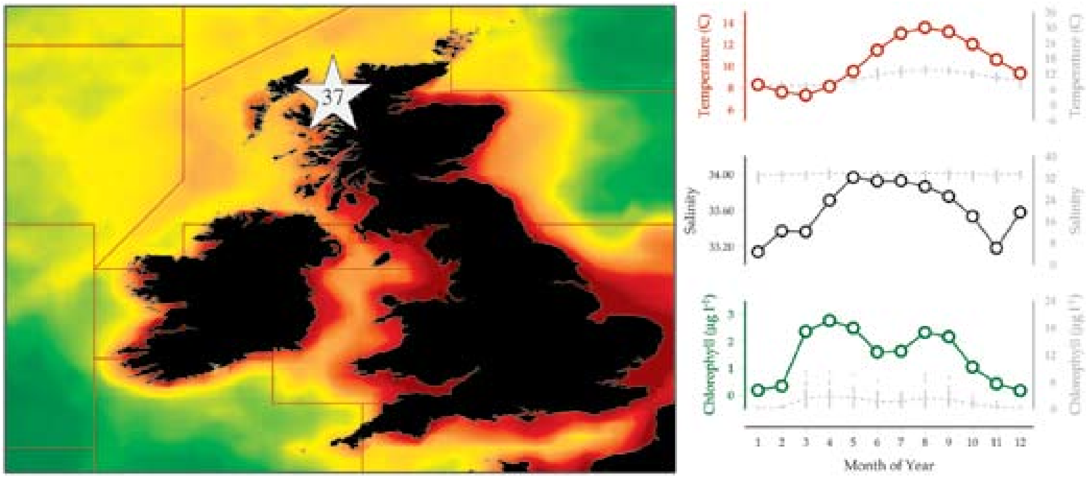


Figure 7.1.1
Location of the Loch Ewe plankton monitoring area (Site 37), plotted on a map of average chlorophyll concentration, and its corresponding environmental summary plot (see Section 2.2.1).

Loch Ewe (Site 37, 57°50.14'N 5°36.61'W), a sea loch on the west coast of Scotland, has been part of the Marine Scotland Science Coastal Ecosystem Monitoring Programme since 2002. This site acts as a reference site to fulfill the requirements of EU Water Framework Directive and to test the development of tools to identify "Good Environmental Status" for the Marine Strategy Framework Directive. Samples have been collected by Isle of Ewe Shellfish and their input to the success of the programme is gratefully acknowledged.

The Loch Ewe monitoring site is 40 m deep and located at the northerly face of the sea loch. Samples are collected weekly. Samples to measure temperature, salinity, and nutrients are collected using a reversing bottle and digital thermometer from surface (1 m) and bottom (35 m) depths. A 10m integrated tube sampler is used to collect samples for chlorophyll and phytoplankton community analysis. Phytoplankton samples are preserved in Lugol's iodine and analysed using the Utermöhl method (Utermöhl, 1958).

Seasonal and interannual trends (Figure 7.1.2)

Water movement in this loch is strongly influenced by wind and tide. The loch faces north and has variable exchange with the North Minch, which is influenced by influxes of Atlantic water. Temperature and salinity show a strong seasonality. The lowest temperatures are observed during spring (ca. 7°C) and the warmest towards late summer. The temperature at this site rarely exceeds 14°C. The temperature at this and other west coast sites can be up to 1–2°C warmer during spring than the sites at the east coast, Orkney, and Shetland. Salinity follows a similar pattern, with lowest salinity observed in spring and highest in late summer.

Nutrients show a seasonal pattern typical to high latitudes, with concentration of total nitrates, phosphate, and silicate accumulating over winter, when phytoplankton abundance is reduced and concentrations decrease during the phytoplankton growing period.

The phytoplankton community observes a similar seasonal pattern to other sites in Scotland, with a strong spring bloom dominated by diatoms. The spring bloom occurs earlier on the west coast (February/March) than on the east (March/April), likely the result of the warmer water temperature. Dinoflagellates become an important component of the phytoplankton community during summer. The autumn diatom bloom is more intensive than on the east coast and is dominated by larger diatoms, such as the *Rhizosolenia* and *Pseudo-nitzschia* spp. type species.

Annual average plots show an increase in dinoflagellates over the last five years. Increased numbers of athecate dinoflagellates have been observed during summer. The pattern of diatom abundance during the spring bloom is similar to that on the east coast, with an increase in abundance of *Skeletonema* observed since 2005 at this site. Chlorophyll data demonstrate an increase, primarily occurring during winter over the last three years. Similar to other sites, a decrease in the abundance of *Ceratium* has been observed over the last decade. This site also experienced a devastating *Karenia mikimotoi* bloom in late summer 2006 (Davidson *et al.*, 2009), with significant mortalities of benthic fauna recorded.

This site was the focus of an intensive study of the presence of shellfish toxin-producing species and algal toxins (Bresnan *et al.*, 2005). Further information and links to the data collected at this site can be found at the Marine Scotland website http://www.scotland.gov.uk/Topics/marine/science/MSInteractive/Themes/Coastal.

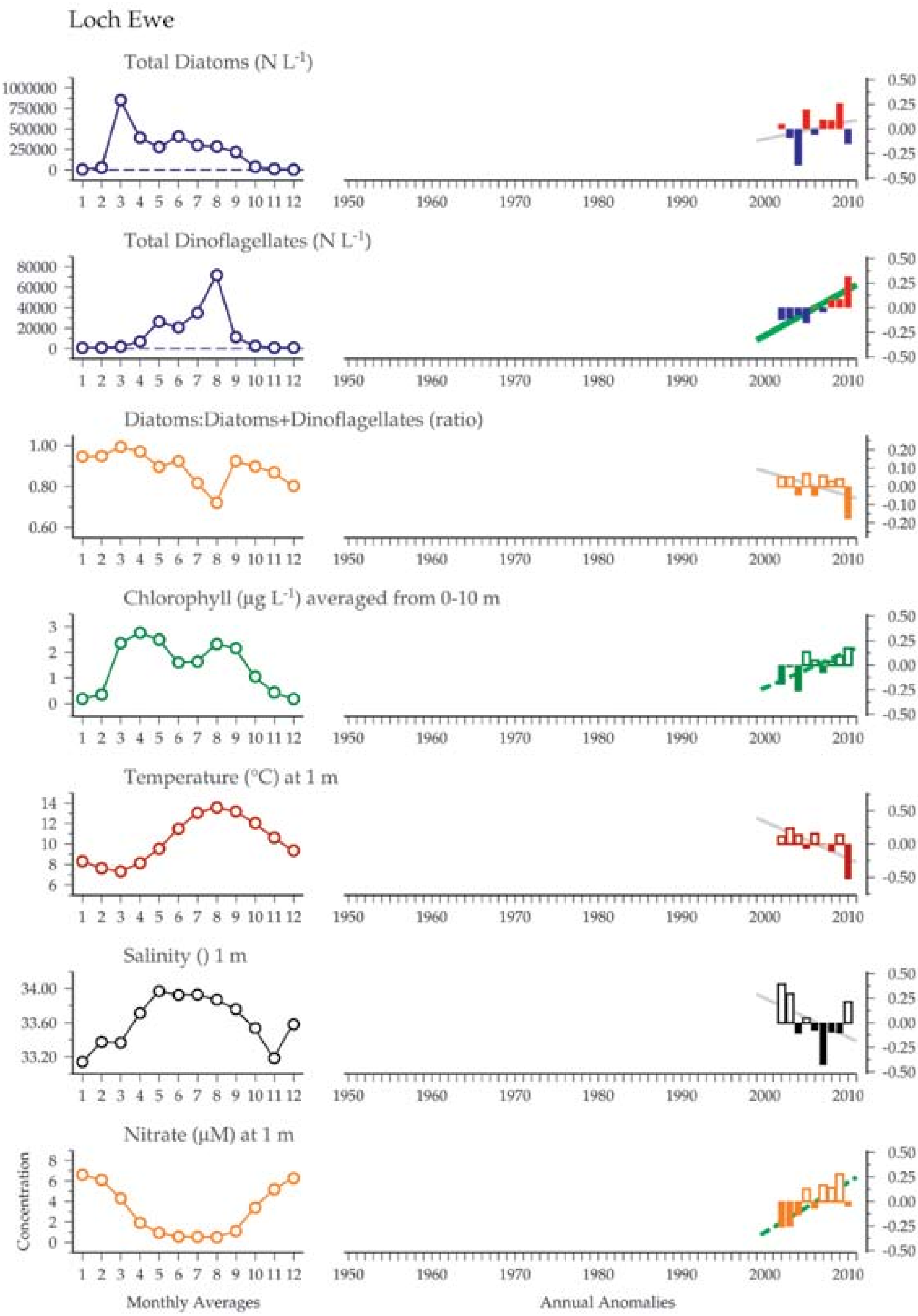
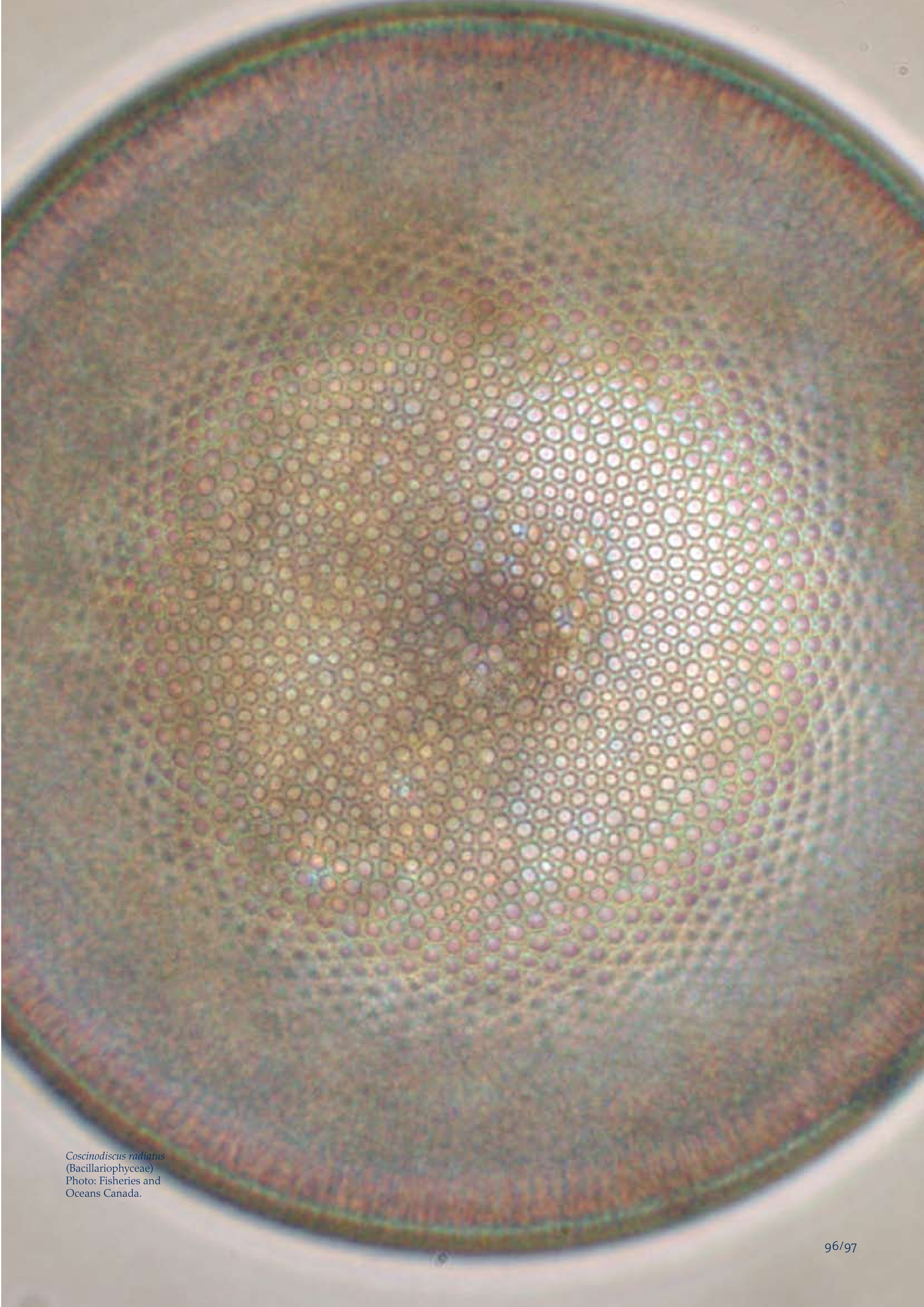


Figure 7.1.2
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the Loch Ewe plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series.



Coscinodiscus radiatus
(Bacillariophyceae)
Photo: Fisheries and
Oceans Canada.

7.2 Loch Maddy (Site 38)

Eileen Bresnan

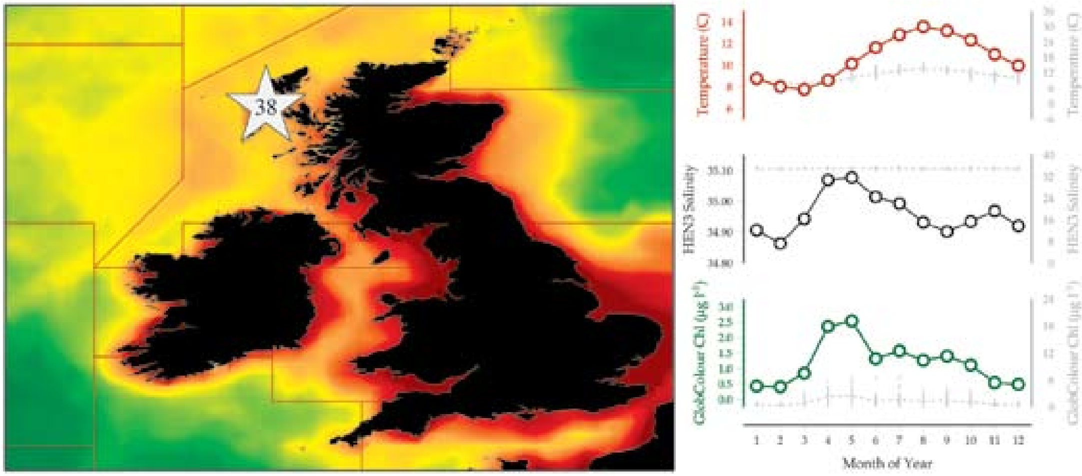


Figure 7.2.1
Location of the Loch Maddy plankton monitoring area (Site 38), plotted on a map of average chlorophyll concentration, and its corresponding environmental summary plot (see Section 2.2.1).

Loch Maddy (Site 38, 57°36.09'N 7°08.48'W) is located on the Island of North Uist, part of the Western Isles. It is a unique site with a diverse saline lagoon system opening into the sea loch, which contains a mix of rocky reefs and soft sediment habitats. This system supports a rich diversity of marine life and, as a result, has been designated a marine special area of conservation (SAC). Loch Maddy has been participating in the Marine Scotland Science Coastal Ecosystem Monitoring Programme since 2003. Samples have been collected by Comann na Mara and Loch Duart Salmon and their input to the success of this programme is gratefully acknowledged.

Temperature is measured using a minilogger, and surface water samples are taken for salinity and chemical analysis. An integrated tube sampler is used to collect samples for phytoplankton community analysis. Phytoplankton samples are preserved in Lugol's iodine and analysed using the Utermöhl method (Utermöhl, 1958).

Seasonal and interannual trends (Figure 7.2.2)

Temperature demonstrates a distinct seasonality, with lowest temperatures in March and warmest in August. The lowest temperatures are observed during spring (ca. 7°C) and the warmest towards late summer. The temperature at this site rarely exceeds 14°C. In common with the other sites from Scotland, this site demonstrates a similar pattern in the seasonality of the phytoplankton community, with a spring bloom of diatoms dominated by *Skeletonema* and *Chaetoceros*. Dinoflagellates become more abundant in summer, and blooms of the dinoflagellate *Prorocentrum balticum/minimum* have been observed during early summer. High abundance of *Karenia mikimotoi* was observed at this site during 2006. In contrast to other sites along the west coast, diatom blooms can occur during summer, and the autumn diatom bloom is not as pronounced. Owing to the relative shortness of the sampling programme, long-term trends in hydrography or biology are not conclusive at this point.

Further information and links to the data collected at this site can be found at the Marine Scotland website http://www.scotland.gov.uk/Topics/marine/science/MSInteractive/Themes/Coastal.

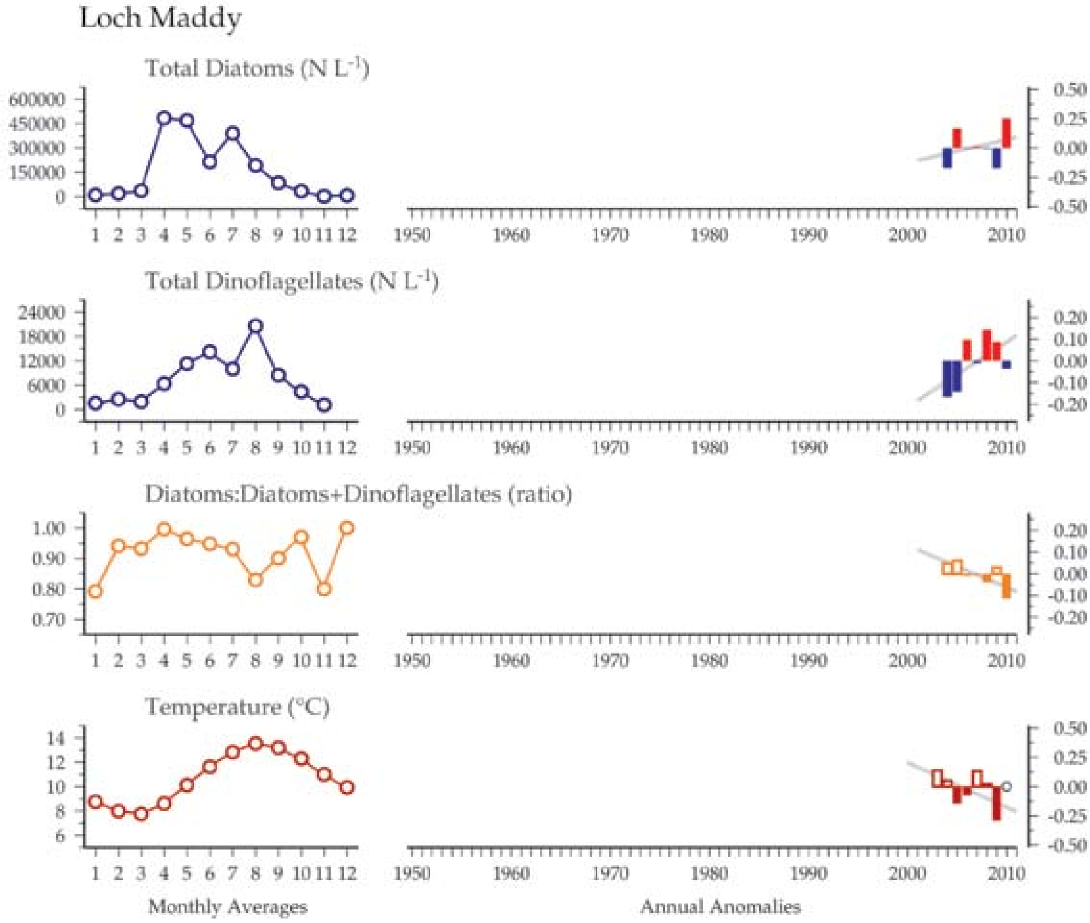


Figure 7.2.2
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the Loch Maddy plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series.

7.3 Millport (Site 39)

Eileen Bresnan

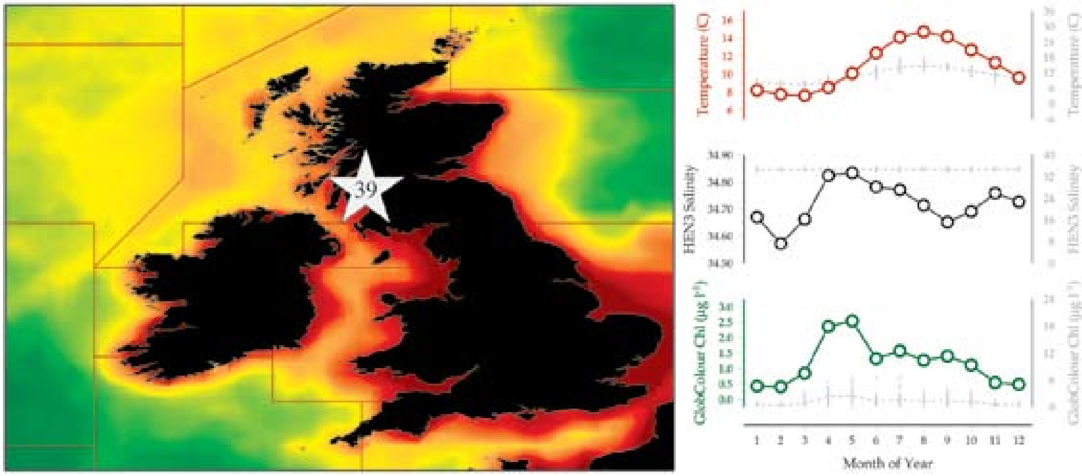


Figure 7.3.1
Location of the Millport plankton monitoring area (Site 39), plotted on a map of average chlorophyll concentration, and its corresponding environmental summary plot (see Section 2.2.1).

Millport (Site 39, 55°44.97'N 4°54.33'W) has been participating in the Marine Scotland Science Coastal Ecosystem monitoring programme since 2005. Samples are collected by the University Marine Biological Station Millport (http://www.gla.ac.uk/centres/marinestation/index.php) and their input to the success of this programme is gratefully acknowledged.

Temperature is measured using a minilogger at Keppel Pier. An integrated tube sampler is used to collect samples for phytoplankton community analysis at Fairlie Channel. The sampling site is approximately 35 m deep. Phytoplankton samples are preserved in Lugol's iodine and analysed using the Utermöhl method (Utermöhl, 1958).

Seasonal and interannual trends (Figure 7.3.2)

Temperature demonstrates a distinct seasonality, with lowest temperatures in March and warmest in August. The phytoplankton time-series at this site is relatively short. A strong phytoplankton spring bloom, dominated by *Skeletonema*, can be observed at this site. Dinoflagellates become more abundant during summer, and large thecate dinoflagellates, such as *Dinophysis* and *Ceratium*, are observed at higher cell densities at this site than at other sites in the programme. Blooms of *Karenia mikimotoi* can be observed during some years. An increase in diatom cell densities during autumn is not observed at this site.

Further information as well as data collected at this site can be found at the Marine Scotland website http://www.scotland.gov.uk/Topics/marine/science/MSInteractive/Themes/Coastal.

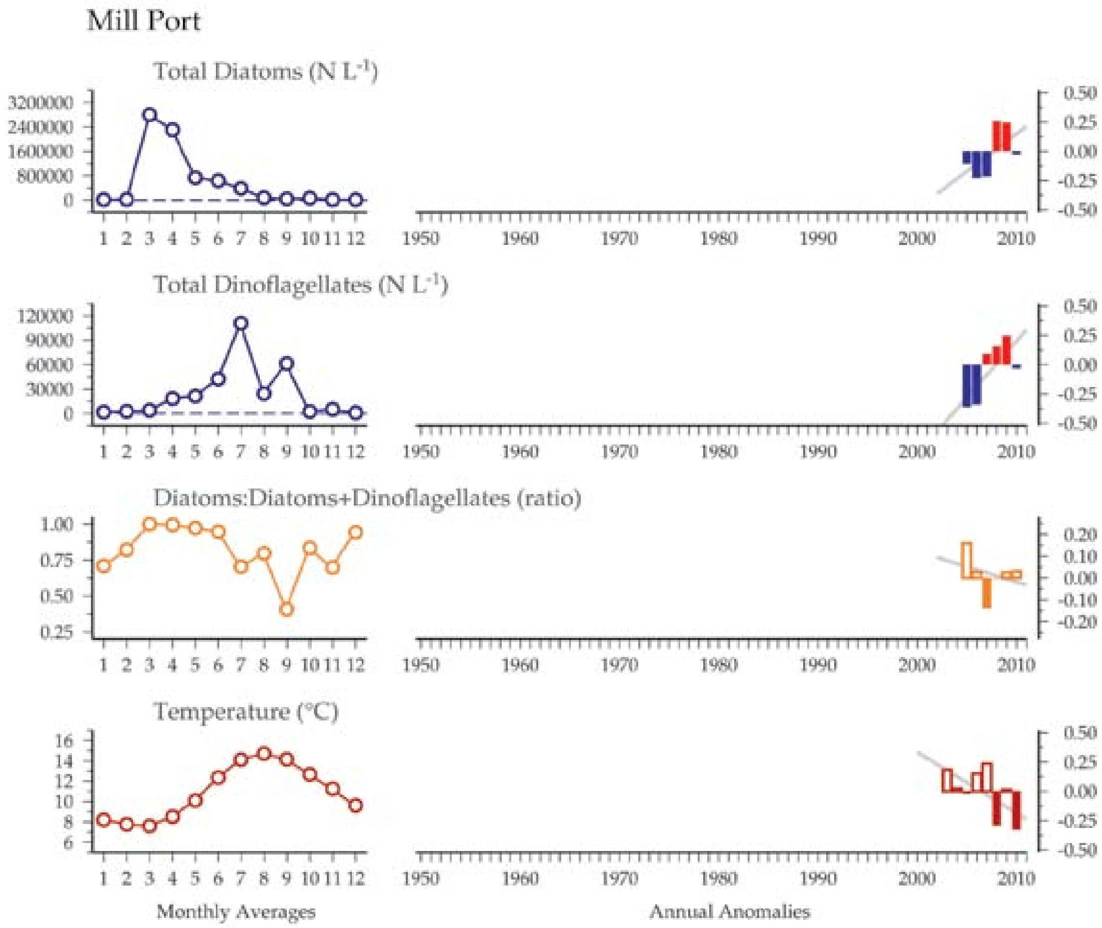


Figure 7.3.2
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the Millport plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series.

7.4 Cypris Station, Isle of Man (Site 40)

Kevin Kennington

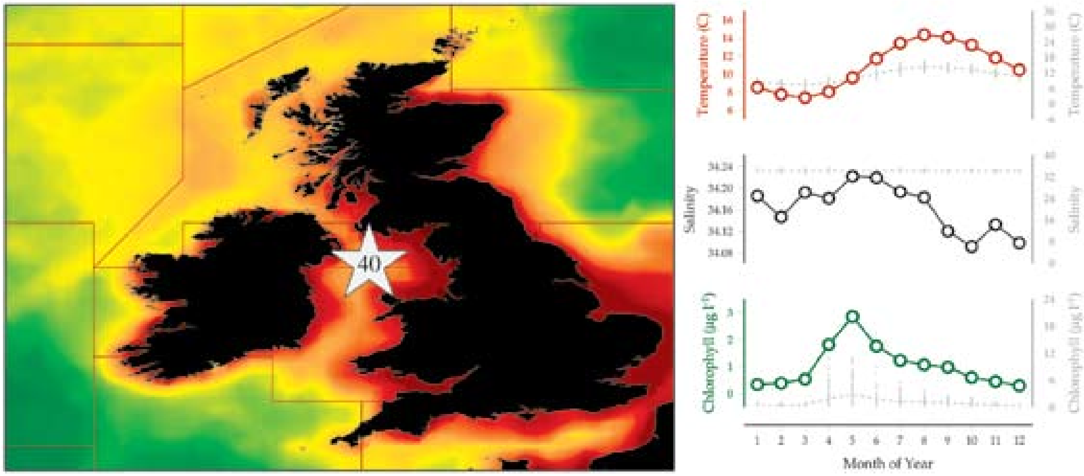


Figure 7.4.1
Location of the Cypris Station, Isle of Man plankton monitoring area (Site 40), plotted on a map of average chlorophyll concentration, and its corresponding environmental summary plot (see Section 2.2.1).

The dataset comprises measurements of temperature, salinity, nutrients, chlorophyll, oxygen, and phytoplankton from two locations near Port Erin (Isle of Man, Irish Sea). Sea surface temperature measurements began to be recorded from the breakwater in Port Erin in 1904. Between 1904 and 2006, SST was recorded twice daily; salinity was also measured at this location between 1965 and 2006. Recordings continue at this location via a digital temperature logger attached to the lifeboat slip in Port Erin Bay. A second station, the so-called "Cypris" station located approximately 5 km due west of Port Erin Bay, was adopted as an offshore monitoring station in 1954. The Cypris data have been collected at frequencies ranging from weekly to monthly, depending on season, boat availability, and weather, and comprise measurements of temperature at 0, 5, 10, 20, and 37 m since 1954: salinity, dissolved oxygen, and phosphate at 0 and 37 m since 1954; silicate at 0 and 37 m since 1958; nitrate and nitrite at 0 and 37 m since 1960; chlorophyll *a* at 0 m since 1966; ammonia at 0 and 37 m since 1992; total dissolved nitrogen at 0 and 37 m from 1996 to 2005; and total dissolved phosphorus at 0 and 37 m from 1996 to June 2002.

At the Cypris station, water samples were collected with either a Nansen–Pettersen or an NIO bottle from 1954 to 2005. Phytoplankton counts have been undertaken on surface samples since 1996. The Nansen–Pettersen bottle was used in conjunction with an insulated thermometer, whereas the NIO bottle was used in conjunction with a mercury reversing thermometer. From 2006 onwards, an RTM 4002 X digital, deep-sea reversing thermometer has been used with an NIO bottle. Salinity was determined by titration against silver nitrate until 1965, thereafter using inductively coupled salinometers (Plessey 6230N until June 1998; Guildline Portasal from July 1998). Nutrients are estimated colorimetrically, and dissolved oxygen is determined by the Winkler technique. Until 2006, chlorophyll *a* was estimated using the trichromatic methods recommended by the SCOR–UNESCO Working Group 17 (SCOR, 1964). Since that year, the spectroscopic methods of Aminot and Rey (2002) have been used. Dissolved nitrogen and phosphorus were measured using the persulphate digestion method adapted from Valderama (1981). The Cypris station data are frequently split into the Cypris I (D. John Slinn) dataset comprising data from 1954 to 1992 and the Cypris II dataset from 1992 to the present.

Data from the Port Erin and Cypris stations are sometimes known collectively as the "Port Erin Bay dataset". Data from Port Erin Bay form part of the Isle of Man GAL Coastal Monitoring Sites network. The data were collected by the Port Erin Marine Laboratory (part of the University of Liverpool) until its closure in 2006. Sampling has since been taken over by the Isle of Man Government Laboratory (Department of Environment, Food and Agriculture). Data collected from Port Erin have been published in several peer-reviewed publications (see reference list).

Seasonal and interannual trends (Figure 7.4.2)

Mean annual sea surface temperature at the site has risen by approximately 0.7°C over the duration of the time-series (1904–2012). These temperature increases follow the broad-scale northern hemisphere atmospheric temperature shifts. Eight of the ten warmest ranked years for local SST have occurred in the last 10 years. There is a positive correlation between the Port Erin breakwater salinity measurements and the North Atlantic Oscillation index (NAO), reflecting the tendency towards warmer European winters during NAO positive years.

No significant long-term trends in salinity have yet been established. Differentials of annual means with reference to the 1966–2010 grand mean have demonstrated a noteworthy period of low salinity around the early 1980s and a period of higher salinity around the late 1990s. Salinity measurements have been below the grand mean since 2002. There is a negative correlation between the winter NAO and Port Erin winter salinity. In NAO negative years, local salinity tends to be less affected by freshwater inputs, reflecting lower precipitation in these years.

Nutrient concentrations are at a maximum during winter. There is considerable interannual variation in the timing of the winter nutrient maxima, which, at the Cypris station, occurs between January and March. In spring, with increasing insolation and phytoplankton growth, stocks of nutrient salts are rapidly depleted, reaching a minimum around late spring. Levels remain low until late summer and early autumn, when organic-decay cycles regenerate nutrient salts to the water column. Winter inorganic nutrient data represent the basal or resting state when biological processes have come to a halt and the regeneration of nutrients is complete.

Phytoplankton analysis at the Cypris station began in 1996 as part of the Isle of Man toxic algae monitoring programme. No significant long-term trends in phytoplankton abundance have been found, which may be the result of the relatively short time-span of the dataseries. The results show that phytoplankton at this site are typical of northern temperate coastal waters. The spring bloom is generally dominated by diatoms, with peak abundance found during April/May. Microflagellated algae can also contribute significantly to the spring bloom and can have peak abundance between April and September. Dinoflagellates have a peak in abundance during summer (July/August), whereas microzooplankton (not shown) are most abundant between May and September.

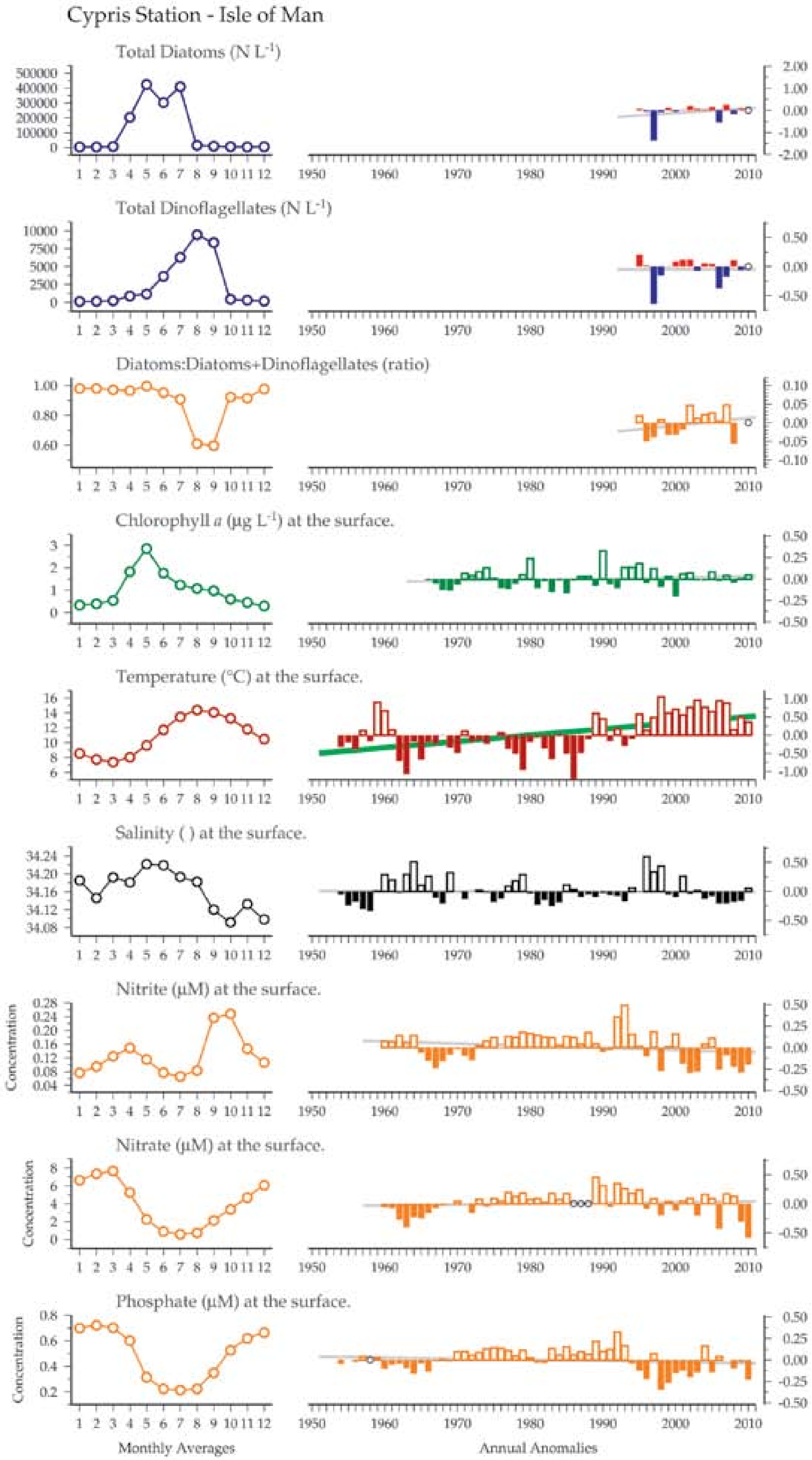


Figure 7.4.2
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the Cypris Station, Isle of Man plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series.

7.5 Irish National Phytoplankton Monitoring (Sites 41–45)

Joe Silke and Caroline Cusack

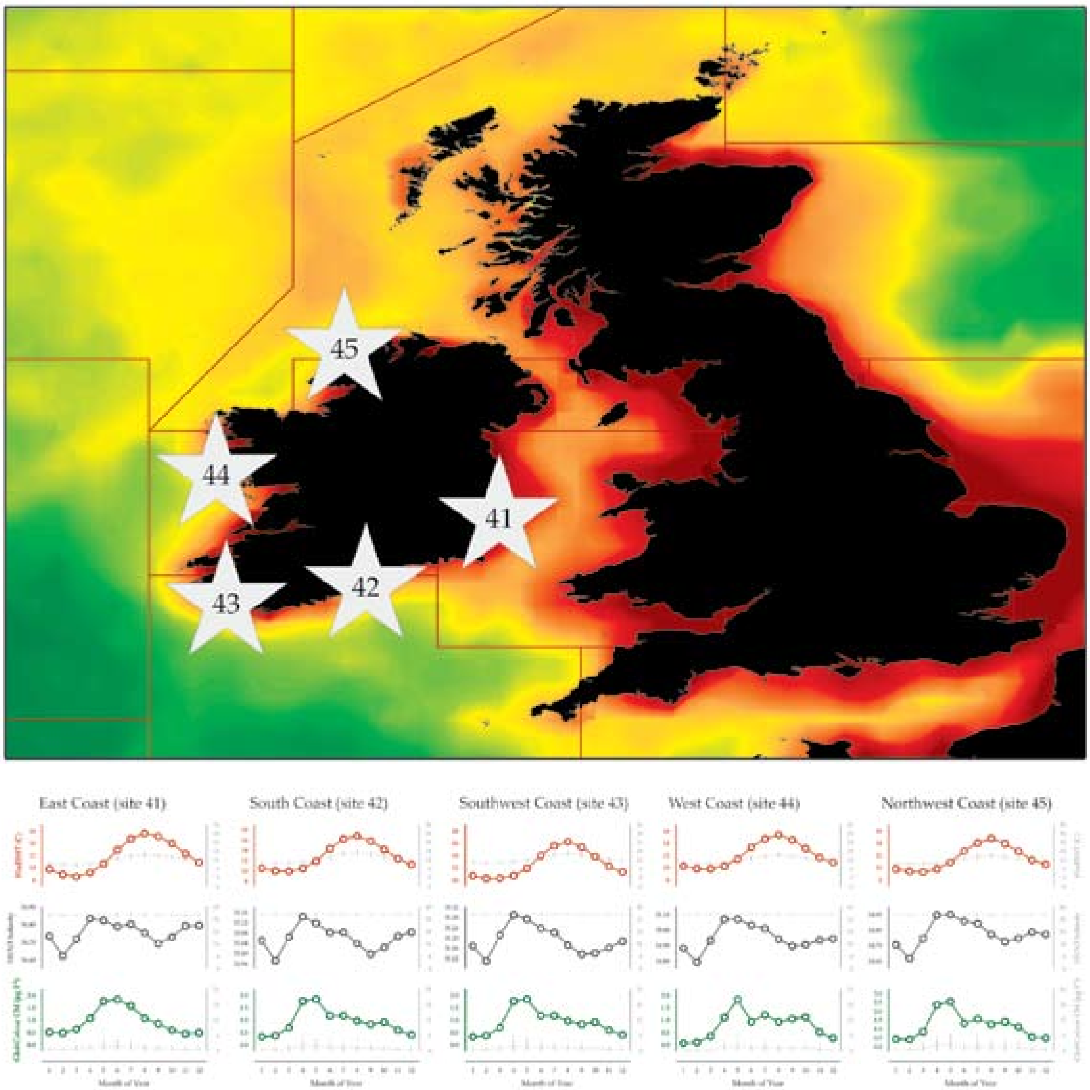


Figure 7.5.1
Locations of Ireland's national phytoplankton monitoring areas (Sites 41–45) area and their corresponding environmental summary plots (see Section 2.2.1).

The Marine Institute in Ireland carries out a national phytoplankton monitoring programme which extends back to the late 1980s. This includes a harmful algal blooms (HABs) monitoring service that warns producers and consumers of concentrations of toxic plankton in Irish coastal waters that could contaminate shellfish or cause fish deaths.

Cusack *et al.* (2001, 2002) summarized the objectives of the monitoring programme. This programme is primarily located along the Atlantic seaboard and Celtic Sea. Scientists working on this monitoring programme have developed an understanding of phytoplankton populations and dynamics around the Irish coastline, especially in relation to those that cause shellfish toxicity. Particular emphasis is put on the detection and enumeration of harmful species; however, the importance of phytoplankton as an indicator of water quality is also studied and is a key component of the European Water Framework.

Since 1990, data have been captured in a systematic manner and logged into an electronic database. Many of the sites were only analysed for toxic and harmful species, because this was the main purpose of the monitoring programme. In addition, however, there were a selected number of sites around the country analysed for total phytoplankton. Over the years, these sentinel sites changed periodically for a number of reasons, mainly the unavailability of persons to take regular samples. Therefore, in order to construct time-series for this report, it was decided to construct regional groups of all of the sentinel sites in the complete database, based on a principal component analysis of the dataset. This resulted in five groups of sentinel sites, which are presented in these maps and graphs as regional locations (Figure 7.5.2). Based on the data extracted and amalgamated from these regions, it is deemed to be a good representation of the phytoplankton flora for these regions. The number of sites used to construct each region varies from region to region, and also within each region over time as sites came and went.

Sites were sampled by a variety of methods, either surface samples, discrete Ruttner sampling bottles, or tube samplers. They were preserved on site with neutral Lugol's iodine, and returned to the laboratory where 25 ml samples were settled for 24 h in Utermöhl chambers before analysis on an inverted microscope. Species were identified and enumerated and cell counts were expressed in cells l^{-1}.

Average sea surface temperatures for western and southern waters of Ireland range from 8 to 10°C in winter to 14–17°C in summer (Lee and Ramster, 1981; Elliott, 1991), and temperatures tend to be several degrees higher compared with the eastern waters. This difference is the result of the entry of warm Atlantic water onto the western Irish Shelf. In winter, Irish coastal and shelf waters are vertically well mixed, with little difference in the surface-to-bottom distribution of temperature within the water column. As the water column stratifies in summer, a surface-to-bottom temperature difference of up to 6°C is typical of waters along the Atlantic Shelf and Celtic Sea (Cooper, 1967; Raine and McMahon, 1998). Along the coast, turbulent tidal currents are sufficient to prevent establishment of stratification, and the water remains mixed throughout the year. The boundary between mixed and stratified waters in summer is marked by tidal fronts that influence the composition and density of phytoplankton community in these areas.

Further information on the sampling programme and results of individual locations can be accessed at the Marine Institute's HABs website http://www.marine.ie/habs.

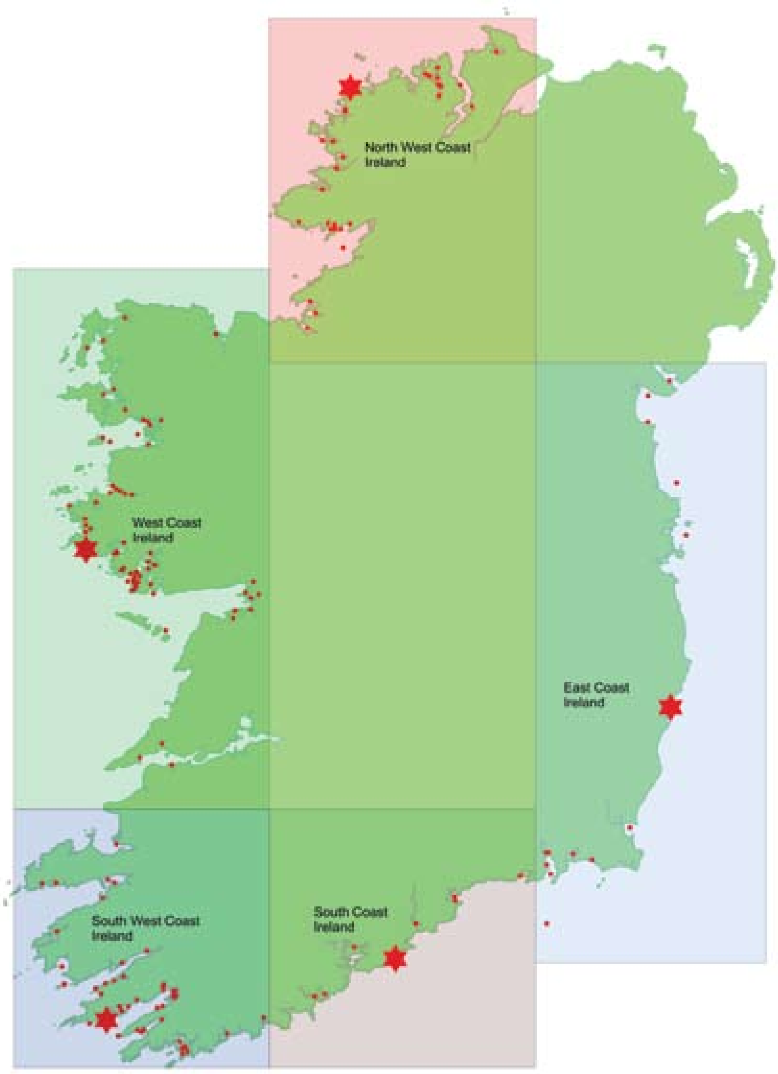


Figure 7.5.2
Combined regions of Irish phytoplankton monitored sites, showing the location of individual sites combined into each region represented in this report.

Seasonal and interannual trends along the east coast (Site 41, Figure 7.5.3)

Seasonal diatom abundances peaked in June, with a second but smaller peak in September. The seasonal abundance of dinoflagellates also peaked in September. The diatoms:diatoms+dinoflagellates ratio is lowest during the warm-water summer period, but the phytoplankton remain dominated by diatoms, such as *Leptocylindrus danicus*, *Chaetoceros* spp., and *Rhizosolenia styliformis*. Total diatom abundance has been decreasing since 1992, possibly correlated with increasing water temperatures over the same period. Long-term trends in the dinoflagellates were inconclusive, following a large peak in the early 1990s.

There is very little shellfish aquaculture along the east coast, apart from the fjord-like inlet of Carlingford Lough, and some mussel fishing in the Wexford and Waterford areas of the southeast coastline. Because of this, there has been limited sampling activity in the region by the Marine Institute for phytoplankton.

There have been some historical studies carried out in the region, notably a study by Gowen *et al.* (2000), where the temporal distribution of phytoplankton and chlorophyll data were described from coastal waters adjacent to the mouth of the Boyne estuary between March and October 1997. During the spring bloom, peak chlorophyll levels up to 11.4 mg l^{-1} were reported during late April–early May. The dominant species at this time was the diatom *Guinardia delicatula*, which represented more than 90% of total phytoplankton abundance (excluding microflagellates). It was also reported that blooms of *Phaeocystis* spp. and other microflagellates occurred before the spring peak in diatoms.

The presence of *Phaeocystis* was also observed occasionally in the Marine Institute time-series with very high counts of up to 48 × 10^6 cells l^{-1} observed in spring and early summer months. Other high counts including *Chaetoceros* spp. (up to 6.2 × 10^6 cells l^{-1}), *Leptocylindrus danicus* (up to 4.2 × 10^6 cells l^{-1}), *Asterionellopsis glacialis* (up to 2.4 × 10^6 cells l^{-1}), and *Prorocentrum balticum/minimum* (up to 2.2 × 10^6 cells l^{-1}) were observed during summer.

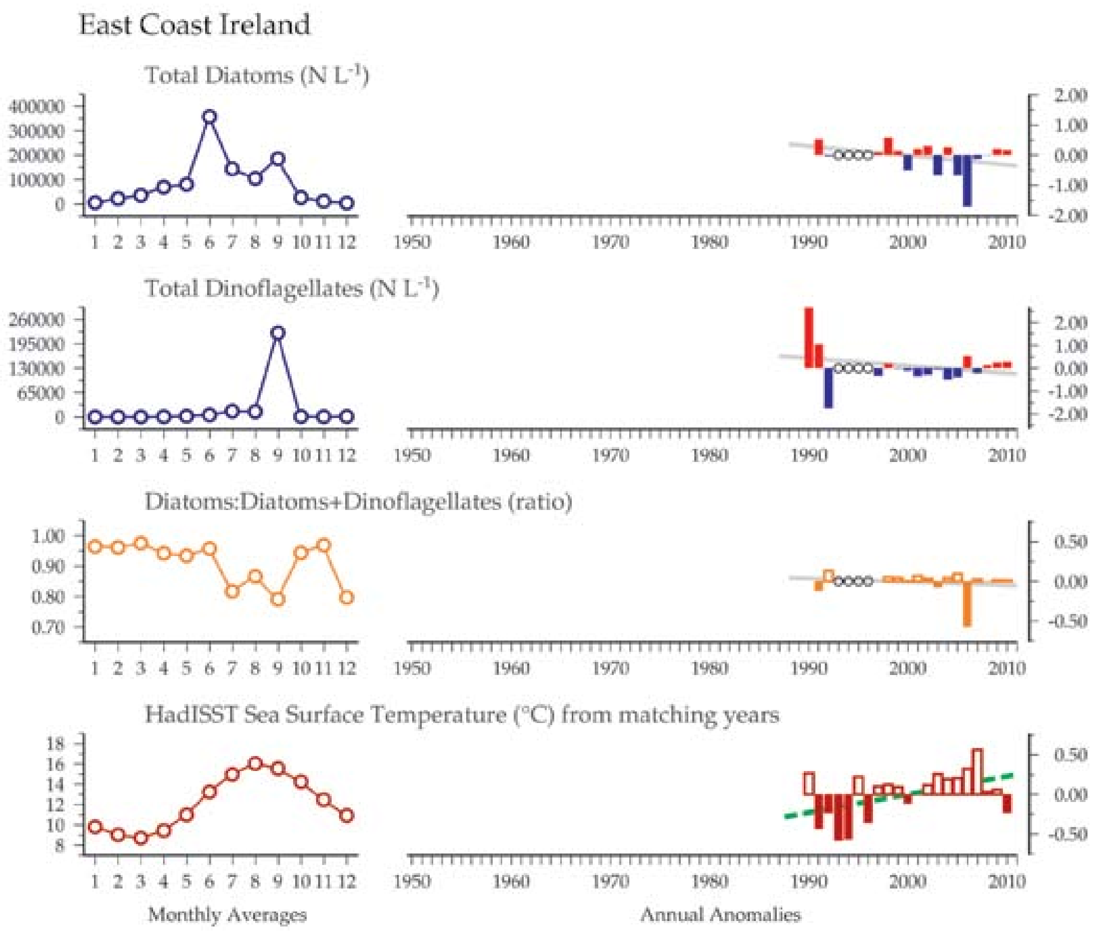


Figure 7.5.3
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the east coast of Ireland plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series.

Seasonal and interannual trends along the south coast (Site 42, Figure 7.5.4)

Seasonal diatom abundance peaked in July/August, with a smaller peak in March/April. The seasonal abundance of dinoflagellates peaked in October. The diatoms:diatoms+dinoflagellates ratio is lowest in June, and has been increasing since 1990. Total diatoms have also been increasing since 1990. Dinoflagellate abundance was variable over this time span, with no clear trend.

Historical information regarding phytoplankton is sparse for this region apart from some studies on *Alexandrium* spp. in Cork Harbour and descriptions of phytoplankton communities in the Celtic Sea. Pingree *et al.* (1976) and Fasham *et al.* (1983) observed that the spring bloom and the seasonal cycle of phytoplankton production in the Celtic Sea are related to the stratification of the water column. Spring blooms develop in April south of Ireland in an area of weak tidal streaming, with increases in phytoplankton biomass tracking the spatial development of stratification. The Celtic Sea Front forms a boundary between mixed and stratified waters of the southern Irish Sea, and there have been some observations of exceptional blooms of *Karenia mikimotoi* during summer on the stratified side of this front (Holligan *et al.*, 1980). This may be a source for blooms that extend around the west coast using the transport mechanism of the Irish Coastal Current to move the bloom around the coast in a clockwise direction, where it establishes blooms as observed in years such as 2005 (Silke *et al.*, 2005). Other large numbers of important dinoflagellates, particularly *Dinophysis acuminata* (up to 125 cells ml^{-1} in July 1992) and *K. mikimotoi* (up to 4300 cells ml^{-1} in August 1994 and 1995), appear to be associated with a region of slack residual flow located off the southern Irish coast. The presence of blooms of toxic species establishing in this area is important for the downstream aquaculture bays to the southwest (Raine and McMahon, 1998).

The north channel of Cork Harbour is also an area of particular note in this region because of the presence of a population of *Alexandrium tamarense* and *A. minutum*. It has been the presence of *A. minutum* (counts of up to 845 000 cells l^{-1}) in this area that has resulted in the only detection of PSP toxins in shellfish in Ireland that exceeded the EU threshold and required closure of the shellfishery (Marine Institute, unpublished data; Touzet *et al.*, 2007).

Notable blooms detected from samples analysed for the national phytoplankton monitoring programme in this region include *Heterocapsa triquetra* (36 × 10^{6} cells l^{-1}), *Prorocentrum balticum/minimum* (20 × 10^{6} cells l^{-1}), *Phaeocystis pouchetii* (16 × 10^{6} cells l^{-1}), *Bacteriastrum* (7.5 × 10^{6} cells l^{-1}), undetermined coccolithophorids (4 × 10^{6} cells l^{-1}), *Leptocylindrus danicus* (3.3 × 10^{6} cells l^{-1}), and *Asterionellopsis glacialis* (3 × 10^{6} cells l^{-1}).

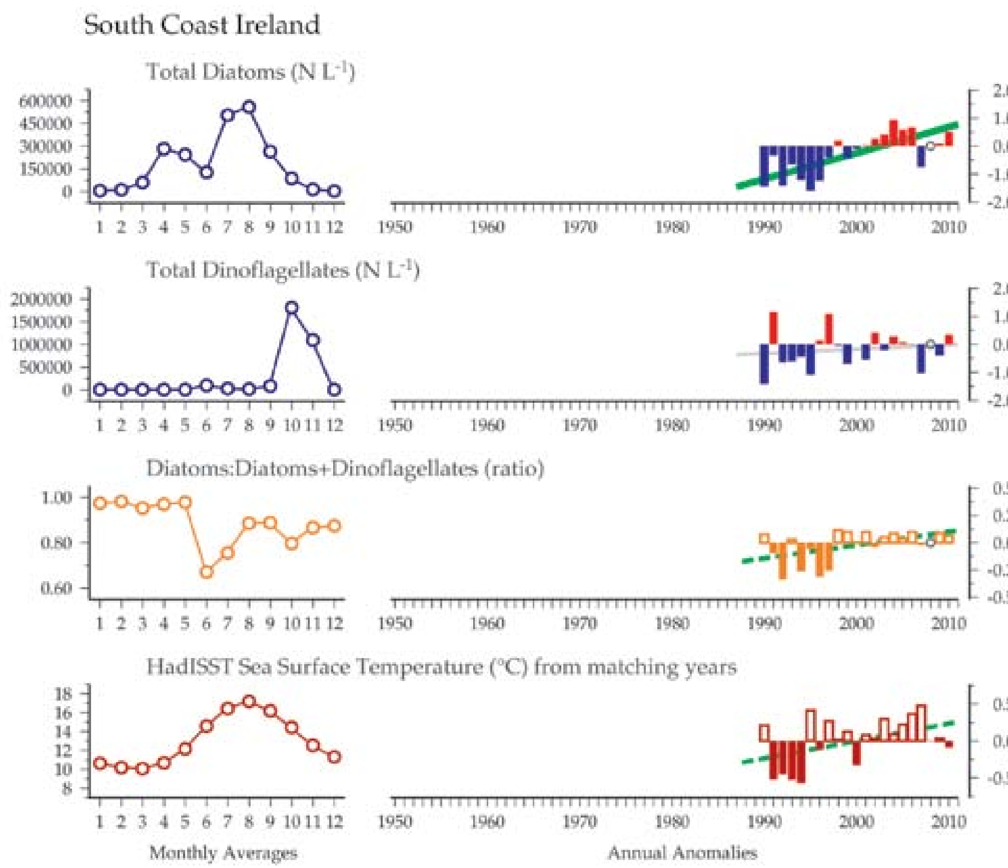


Figure 7.5.4
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the south coast of Ireland plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series.

Seasonal and interannual trends along the southwest coast (Site 43, Figure 7.5.5)

Seasonal diatom abundance peaked in May and July, whereas dinoflagellates peaked in September. The diatoms:diatoms+dinoflagellates ratio is lowest in August, and has been increasing since 1990. Total diatoms have also been increasing since 1990, whereas dinoflagellate abundance has been variable over this time-span, with no clear trend.

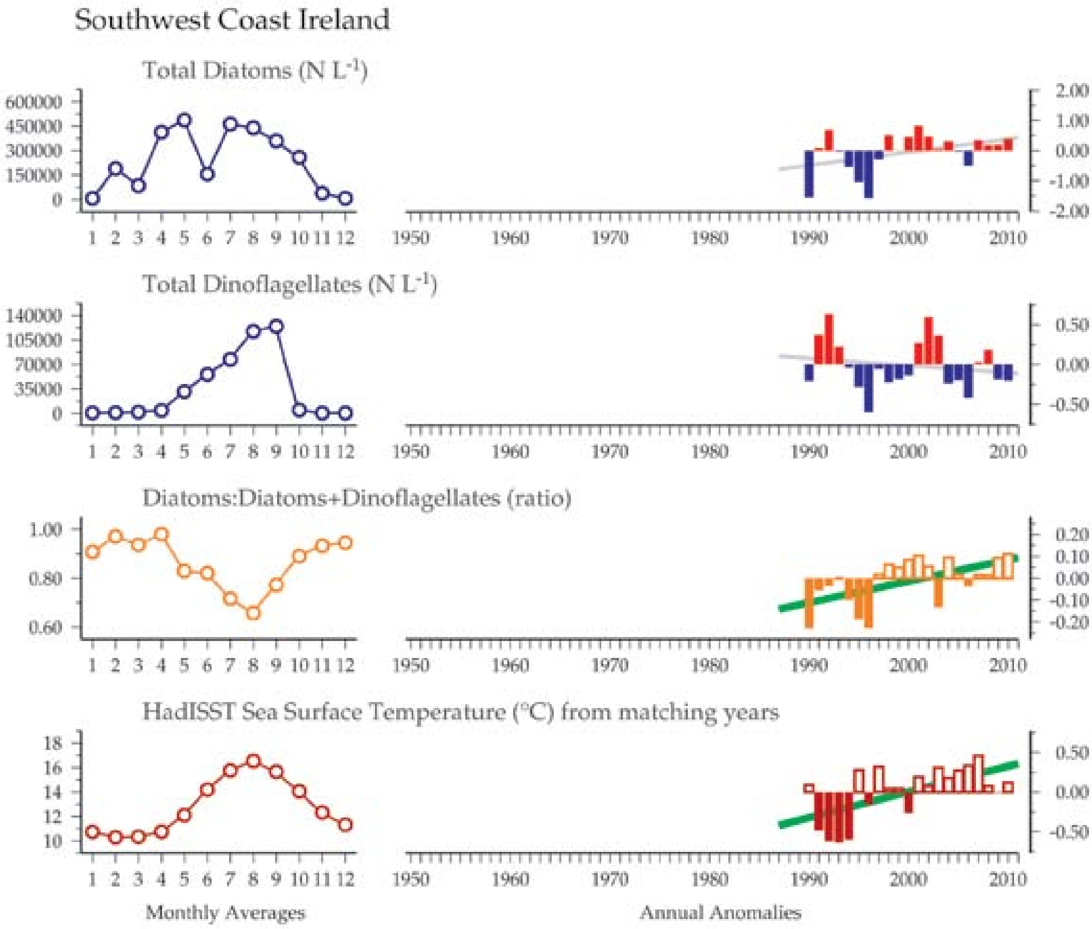
This area is dominated by a series of embayments (similar to the Gallician rías of northwest Spain) along the coast, which are glacial-flooded river valleys, orientated in a northwest–southwest direction. These sheltered bays have become the location for a successful shellfish aquaculture industry, predominated by the culture of blue mussels (*Mytilus edulis*). Rope culture in these bays accounts for 80% of the national production. The hydrography of the areas is characterized by coastal upwelling, which is highly variable in both its periodicity and magnitude. During periods when there is stable water structure in this area, the microalgal flora is typical of the greater Atlantic Shelf area. The other key feature of this area was described by Raine and McMahon (1998), who noted that the composition of phytoplankton in samples collected from shelf waters off the southwest coast between 1992 and 1995 changed markedly in relation to the position of the Irish Shelf Front. It has been demonstrated that the sudden appearance of blooms such as *Karenia mikimotoi* resulted from advection of offshore populations into the southwest bays. The transport mechanism of these blooms was not known until the presence of the seasonal jet-like Irish Coastal Current was established (Fernand *et al.*, 2006). The strength of this clockwise flow around the southwest tip of Ireland is modulated by the presence of the Shelf Front, which is close to the shore in the presence of dominant southwesterly winds. When these winds relax, the front is weakened and the Irish Coastal Current can establish, bringing populations of dinoflagellates from the Celtic Sea to the mouth of the southwest bays, where they can be advected inshore by wind-induced residual flow in a two-layered stratified system (Edwards *et al.*, 1996).

Historically, there have been several studies of the plankton in this region, owing to the aquaculture presence and importance to the regional economy. A study by Raine *et al.* (1990) presents results of investigations into the distribution of phytoplankton for coastal waters off the southwest coast of Ireland during summers of 1985–1987. In general, diatom populations were associated with the cooler regions, whereas dinoflagellates tended to predominate in stratified water. In 1985 and 1987, during upwelling events, diatoms dominated the flora in the vicinity of the Fastnet Rock and west of Bantry Bay, particularly species such as *Chaetoceros* spp., *Leptocylindrus danicus*, *Guinardia delicatula,* and *Thalassiosira* spp. In 1987, *Rhizosolenia alata* was the dominant diatom species. Farther offshore, where the water column was more stratified than in the previous two years, dinoflagellates increased in numbers, but *Proboscia alata* was still numerically dominant.

The National Monitoring Programme has identified some very dense blooms of diatoms and dinoflagellates between 1990 and 2010. These have included *Rhizosolenia* spp. (75 million cells l^{-1}) in July 1991, an unidentified *Microflagellate* sp. bloom (53 × 106 cells l^{-1}) in October 2007, and a bloom of *Skeletonema* spp. (26 × 10^6 cells l^{-1}) in May 1998. Other less numerically dense, but still significant, blooms included periodic blooms of *Phaeocystis* spp. (up to 17 × 10^6 cells l^{-1}), *Leptocylindrus minimus* (up to 12 × 10^6 cells l^{-1}), *Cylindrotheca closterium/Nitzschia longissima* (up to 10 × 10^6 cells l^{-1}), *Skeletonema* spp. (up to 9 × 10^6 cells l^{-1}),*Thalassionema nitzschioides* (up to 5.5 × 10^6 cells l^{-1}), *Noctiluca scintillans* (up to 5.2 × 10^6 cells l^{-1}), and *Thalassiosira* spp. (up to 4.8 × 10^6 cells l^{-1}).

Blooms of *Dinophysis acuta* and *D. acuminata* were observed in the bays during most summers, but never in particularly dense blooms or dominating the phytoplankton community. They are of particular note, however, because they resulted in closures of shellfish farming most years, for periods of time ranging from weeks to several months. The transport mechanism of the Irish Coastal Current and its control by the Irish Shelf Front is believed to be important in the delivery of *Dinophysis* to these aquaculture bays (Raine *et al.*, 2010).

Figure 7.5.5
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the southwest coast of Ireland plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series.



Seasonal and interannual trends along the west coast (Site 44, Figure 7.5.6)

Seasonal diatom abundance peaked in August, followed by a dinoflagellate peak in September. The diatoms:diatoms+dinoflagellates ratio is lowest in July. Diatoms, dinoflagellates, and their ratio have been increasing since 1990, but none of the trends were statistically significant.

The west-of-Ireland region covers the coastline from the mouth of the Shannon River north to the northern coastline of County Mayo. This area is made up of exposed coastline open to the Atlantic Shelf waters to the west, and several coastal embayments offering sheltered shallow waters, where both shellfish farming and finfish farming industries have successfully operated.

The spring phytoplankton of the area is typical of that investigated by O'Boyle (2002), who reported that the spring bloom in Galway Bay occurred in mid-April, when a maximum chlorophyll concentration of just over 11 mg l^{-1} was recorded. The spring bloom was dominated by diatom species including *Thalassiosira* spp. and *Chaetoceros* spp., with maximum cell numbers of 167 and 39 cells ml^{-1}, respectively. In May, this assemblage was replaced by other diatom species, such as *Dactyliosolen fragilissima*, *Leptocylindrus danicus*, *Leptocylindrus minimus*, *Pseudo-nitzschia* spp., and *Ceratualina pelagica*. Microflagellates were common throughout the study period, with cell numbers ranging from 2 to 27 × 10^3 cells ml^{-1}.

Summer distribution of phytoplankton in Atlantic Shelf waters west of Ireland was reviewed by Raine *et al.* (1993), who concluded that the pattern of change in phytoplankton populations can be divided into two temporal phases separated by the full development of the thermocline, which can obtain a depth of 35–40 m by mid-July. In early summer, before the water column becomes fully stratified, intermittent vertical mixing promotes a series of diatom blooms that are usually dominated by *Chaetoceros* spp. and *Rhizosolenia setigera*, with dinoflagellate numbers remaining low, with the possible exception of *Scrippsiella*. Following stratification, these species are replaced by dinoflagellates including *Ceratium* spp., and also the diatoms *Proboscia alata* and *Leptocylindrus mediterraneus*.

A notable bloom in 2005 of *Karenia mikimotoi* extended along the west coast for most of the summer and resulted in severe benthic in-faunal and pelagic mortalities of macroinvertebrates and fish (Silke *et al.*, 2005). A second bloom was detected in a later period of summer in the southwest, and was present the following year on both the east and west coasts of Scotland.

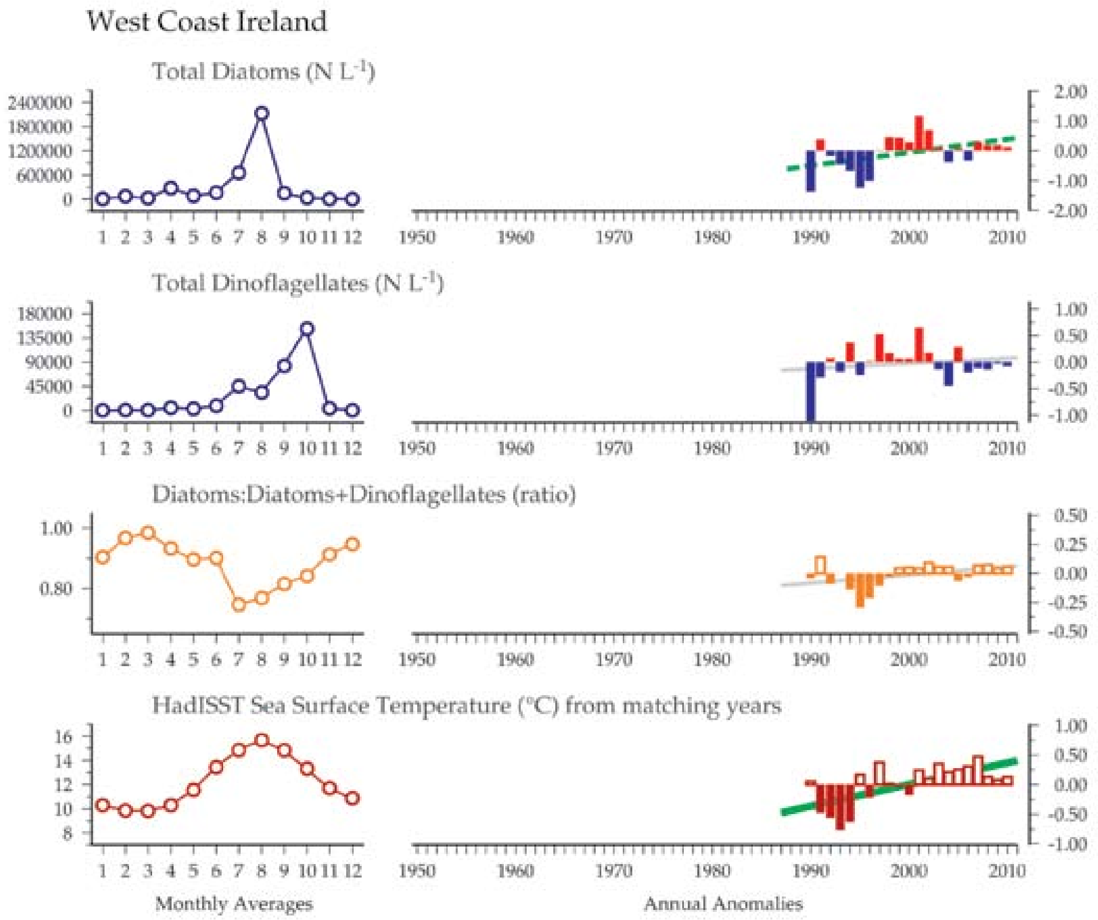


Figure 7.5.6
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the west coast of Ireland plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series

Seasonal and interannual trends along the northwest coast (Site 45, Figure 7.5.7)

Seasonal diatom abundance peaked in March and July, whereas dinoflagellates peaked in November. The diatoms:diatoms+dinoflagellates ratio is lowest in November/December. Diatoms have been increasing since 1990. Dinoflagellates also show a positive, but non-significant, trend. The diatoms:diatoms+dinoflagellates ratio was almost completely flat at this site.

This region represents sites from Sligo Bay up to the most northerly bay in Ireland: Trabreaga Bay. The rugged coastline of Counties Sligo and Donegal represents a diverse environment ranging from long shallow sandy bays of Sligo and sheltered coves along the north coast, to exposed bays and rocky shorelines in Donegal. These waters are all fully saline, with little significant freshwater input in the region.

The distribution of phytoplankton in this area has been demonstrated to be related to the main oceanographic features of the region (O'Boyle and Raine, 2007). In that study, the authors presented the results of observations along the northwest coast in 1999. Inshore of the Irish Shelf Front, the phytoplankton species composition was dominated by diatoms, such as *Leptocylindrus danicus, Guinardia flaccida*, and *Pseudo-nitzschia* spp. The flora of the shelf region between the front and the outer shelf was characterized by the presence of *Halosphaera minor, Oscillatoria* sp., *Ptychodiscus noctiluca, Ceratium fusus*, and *Amphidoma caudata*. Farther offshore along the margins of the continental shelf, the floral assemblage was marked by the presence of *Gonyaulax polygramma, Ceratium furca, Oxytoxum scolopax, Podolampes palmipes, Prorocentrum compressum*, and *Prorocentrum dentatum*. The highest *Karenia mikimotoi* cell concentrations of up to 100 cells ml^{-1} were found in proximity to bottom density fronts located inshore. Chlorophyll *a* concentrations (not shown) are generally low at 1.0 mg l[–1] throughout the survey area, with the exception of some inshore coastal stations where values ranged from 1.8 to 3.4 mg l[–1], particularly in inlets along the west coast of Donegal.

The data extracted from the Marine Institute database demonstrates that coastal areas exhibit periodic blooms of both diatoms and dinoflagellates. The most frequent of these were *Asterionellopsis* spp., with cell counts above 14 × 10^6 cells l^{-1}. A significant dinoflagellate bloom of *Prorocentrum balticum* occurred off the north coast in 1997, with counts of up to 11 × 10^6 cells l^{-1} recorded. Other notable diatoms in this area include *Chaetoceros* spp. and *Skeletonema* spp., which have frequently bloomed with densities recorded up to 17 × 10^6 cells l^{-1}. Dinoflagellate blooms are also recorded in this region, including blooms of *Heterocapsa triquetra, Gymnodinium* spp., and *Karenia mikimotoi*.

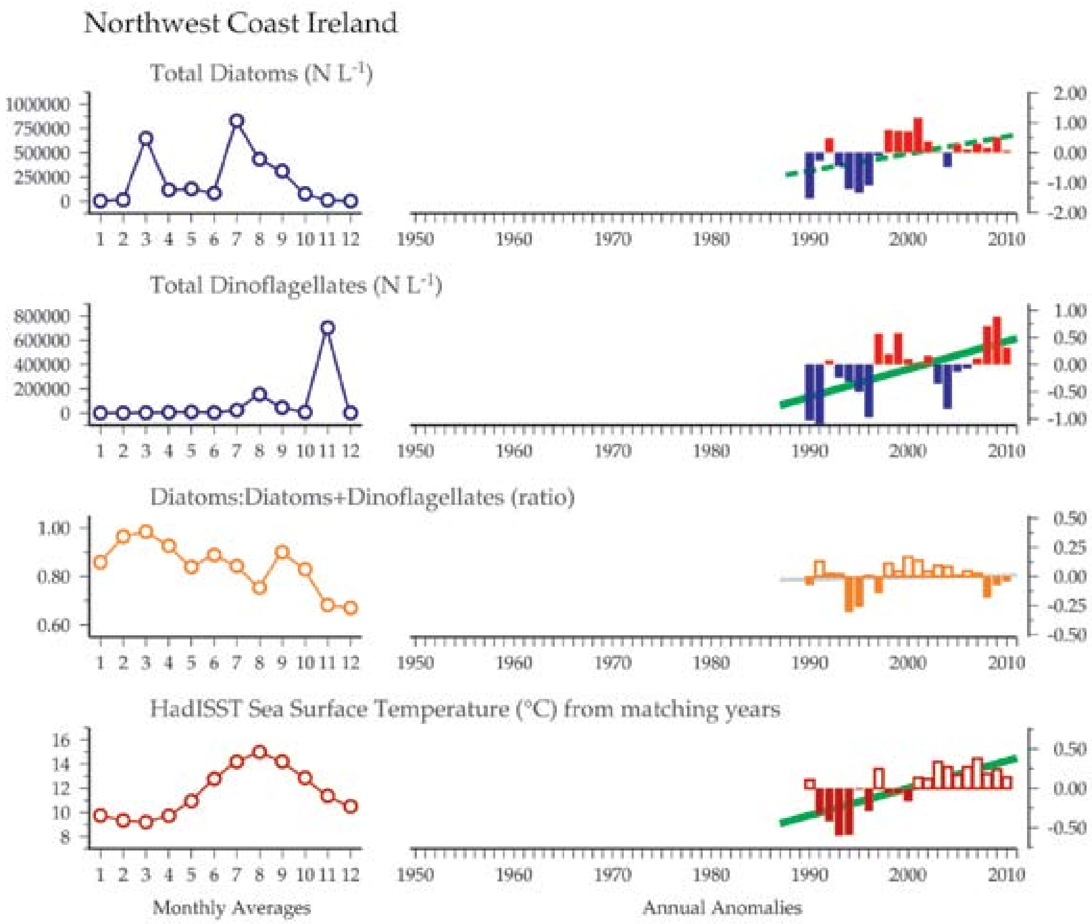
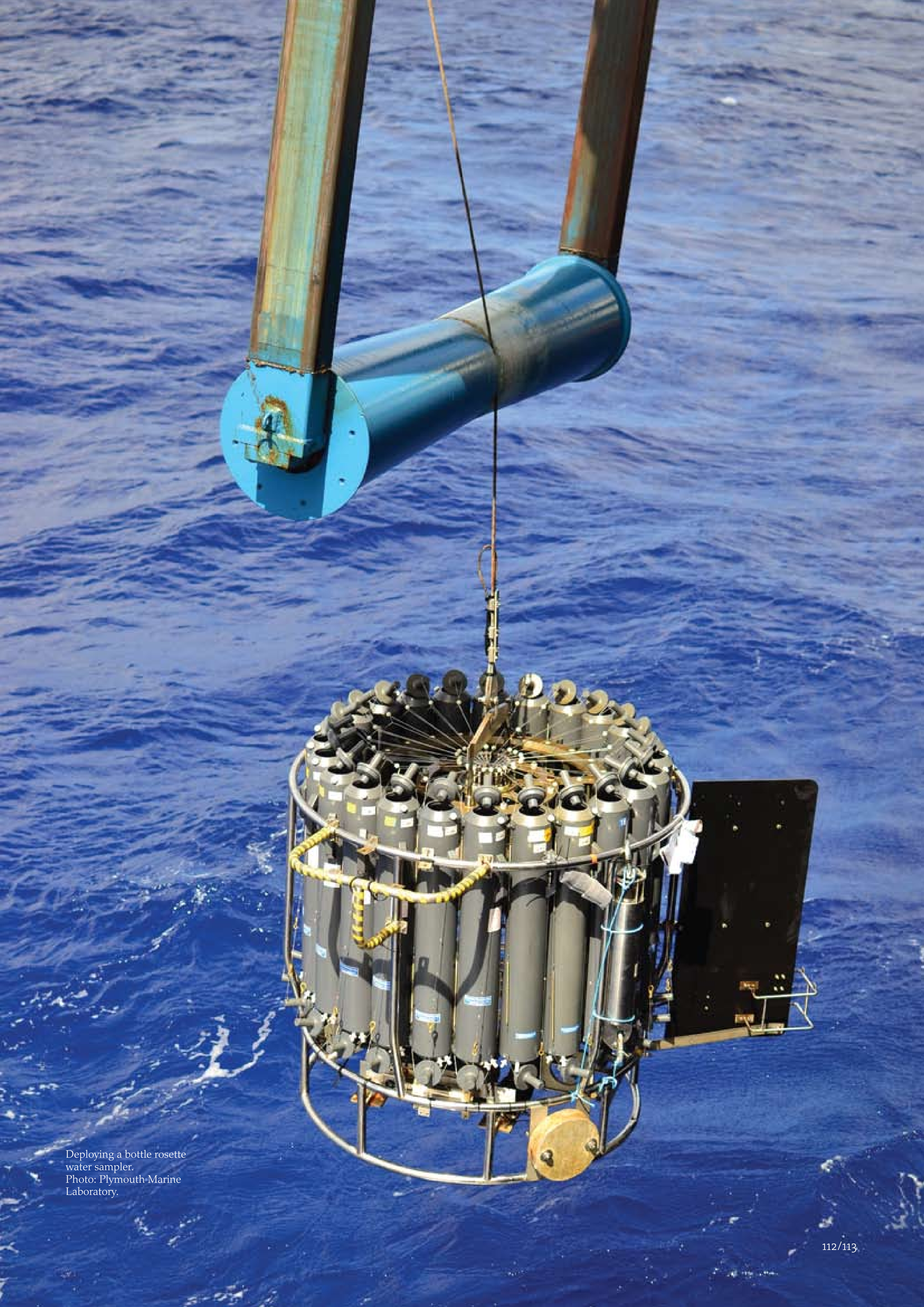


Figure 7.5.7
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the northwest coast of Ireland plankton monitoring site. Additional variables from this site are available online at http://wgpme.net/time-series.



Deploying a bottle rosette water sampler.
Photo: Plymouth Marine Laboratory.